LCA Case Studies

LCA of Finer Sand in Concrete

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Abstract

Goal, Scope and Background. Due to the limited spatial possibilities for the extraction of coarse sand available from land sources, and the abundant availability of finer sands in land and marine sources, the Dutch government aims to allow for the use of finer sand used in the Netherlands. The application of finer sand in concrete requires adaptations in the concrete composition (additional cement, additional superplasticiser, or other aggregates) to maintain workability. In order to examine if these adaptations result in shifts from (the expected) land use effects to other environmental effects, an LCA of finer sand in concrete was carried out.

Methods. Besides the common CML-method, an experimental characterisation method for land use, was applied.

Results and Discussion, Conclusion. The results show that the application of finer sand indeed results in lower land use effects. Compositions with additional cement and other aggregates result in somewhat higher scores on the usual CML impact categories. Compositions with extra superplasticiser result in roughly similar environmental effects as the current compositions.

Recommendation and Perspective. The conclusions were used to formulate recommendations for the national policy on fine sand in concrete. Due to a change in priorities, it is not sure if and which organisation will use the conclusions.

Keywords: Concrete; finer sand; land use

Introduction

Concrete consists of cement, aggregates and water. Gravel and sand are the main aggregates applied in the Netherlands. Sand for concrete is obtained by sorting natural sand; the coarser particles are used for concrete, the finer particles are sold as filling material or simply backfilled. The use of finer sands in concrete is currently very limited due to technical complications. Recent research showed that application is possible if the traditional concrete composition is adapted [1]. Possibilities are adding superplasticiser, extra cement or aggregates with different properties next to the finer sand.

Application of fine sand in concrete increases the added value of fine sand. Furthermore, more geological resources (containing mainly fine sand) in the Netherlands could become attractive for exploitation, e.g. marine sands in the North Sea area. A more efficient use of sand is important for the Netherlands since sand extraction from land based excavation sites has large spatial and societal impacts in this densely populated country.

The adaptations in the concrete composition influence the environmental performance of concrete. The expected positive land use effects could result in a shift to other environmental effects. In this paper we describe the LCA approach, the results and an evaluation of the LCA study [2] in which land use effects were included as an experiment.

1 Goal

Goal of the LCA was to identify the environmental benefits and drawbacks of the application of finer sand in concrete, and to advice on the stimulation of the use of sand in concrete.

The two central questions were:

1. Should the application of finer sand in concrete be stimulated, based on the LCA?
2. If so, which sand types from which origin are preferred?

Target group of the LCA are national policy-makers. The sand and concrete industry are important stakeholders.

2 Project Approach

The LCA was carried out according to ISO 14040-43. An important element for a comparative public LCA study like this one, is the panel review. A panel of stakeholders was established, consisting of representatives from the sand and concrete industry and national and regional policymakers. The panel was chaired by an independent chairman who is familiar with the political discussions about sand. The panel also included an independent LCA expert to review the methodological content.

The panel was asked to comment on three occasions (stages during the project): on the goal and scope (written), on the preliminary results and possible subjects for the sensitivity analyses (a meeting preceded by an LCA explanation), and on the draft results (meeting).

3 LCA Approach

3.1 Functional unit

The following functional unit was used:

'The production of 1 m^3 ready-mixed concrete B25 exposure class 2, consistency class 3, in applications where no additional constructive measures (like reinforcement) are required'.

Ready-mixed concrete is concrete that is mixed in a plant and directly transported to the building site where the concrete is poured into formwork. 'B25 … class 3' reflects the technical performances of the concrete. Concrete can be reinforced. For specific situations additional reinforcement (constructive measures) may be required, but this is not common and is therefore not considered.

This B25 concrete type was chosen, because the technical application of finer sand in this type is proven [1]. Furthermore, this type is the most applied concrete mortar type in the Netherlands. A typical B25 composition was chosen, which is regarded as representative in order to draw more general conclusions about finer sand in concrete.

One cubic metre of concrete was chosen as reference amount. The central questions to be answered refer to the whole Dutch concrete market. However, linear scaling from 1 m^3 is not possible. The application of finer sand in concrete could result in shifts (substitution) in the market of filling materials. Such effects were disregarded because of the complexity; theoretically, market changes have influence anywhere in the North West European raw materials sector. However, huge shifts are not likely [6].

The LCA was restricted to a cradle-to-gate study. The gate-to-grave tree is similar for all compositions, since the concrete performance must meet the B25 requirements. The volume (which influences transport) and recycling possibilities of the compositions are similar, too. Leaching in the use phase was not studied explicitly and not taken into account, since it is expected that the leaching behaviour does not differ significantly and all compositions meet the Dutch legal limits for leaching.

3.2 Product system

21 concrete compositions were studied, as mentioned in **Table 1**. Concrete containing the usual Dutch coarse sand, from a typical location, was used as a reference (no 1).

3.3 Data collection

Primary data on sand extraction were collected in co-operation with some representative companies. The primary data concern mainly energy consumption and land use data. Other input data stem from literature and public sources (DIK LCA-database). For land use data we used the data from Lindeijer [3] which are included in the IVAM 4 database [4].

Collection of land use data at companies has proven to be challenging. Extraction of raw materials on land is often a dynamic process in time, when looking at the occupation and function of an area. Specific data regarding land use are normally not collected and stored within the companies. Data concerning extraction of marine sediments are even more difficult to lay hands on. Therefore, only fairly rough data have become available through interviews.

3.4 Allocation

The extraction of sand is regarded as a multi-output process, which results in several fine and coarse sand fractions. At first we tried to avoid allocation by detailing the process and looking at specific processing routes for every fraction (theoretically finer sand could give a higher yield per ton of

Table 1: Overview of concrete compositions

Code	Sand type	Correction	Code	Sand type	Correction	Code	Sand type	Correction
1	Land 28/92		7	Marine 28/92 (UK)		12	Marine 2/55	170 kg CR (B)
2a	Land 15/74	0.2% SP	8a	Marine 15/74	0.2% SP			
2b	Land 15/74	0.5% SP	8b	Marine 15/74	0.5% SP	13	Marine 2/55	0.5% SP 170 kg CR (B)
3a	Land 15/74	30 kg C	9a	Marine 15/74	30 kg C	14a	Marine 2/55	30 kg C 170 kg CR (B)
3b	Land 15/74	50 kg C	9b	Marine 15/74	50 kg C	14b	Marine 2/55	50 kg C 170 kg CR (B)
4a	Land 2/55	1.0% SP	10	Marine 2/55	1.5% SP			
4b	Land 2/55	2.3% SP						
5	Land 2/55	70 kg C	11	Marine 2/55	70 kg C			
6	Land 28/92 (PL)					15	Marine 2/55	170 kg CR (N)

Notes:

- The reference composition (code 1) consists of 740 kg sand, 300 kg cement, 165 kg water and 1180 kg gravel.
- A sand type like 28/92 means that 28% remains on a 1 mm sieve and 92% on a 250 μm sieve.
- SP = superplasticiser (any of the four main groups of superplasticisers: sulphonated naphthalene formaldehyde, sulphonated melamine formaldehyde, vinyl copolymers or poly carboxylic ethers), C = (blast furnace slag) cement, CR = crushed rock 2-6 mm (170 kg CR replaces 25% of the sand fraction in concrete compositions 12–15)
- Origin of the compounds is the Netherlands, unless noted: (UK) from the British continental shelf; (B) from Belgium; (PL) from Poland; (N) from Norway

natural sand). However, this was practically not possible. Therefore, allocation could not be avoided. Since the prices differ significantly, allocation on an economic basis was considered more appropriate than mass allocation. A drawback of this approach is that the prices are determined by market mechanisms (availability and demand) more than by process-related factors. If fine sand would be applied in concrete, the price may increase. Whether the price will rise to the same level as coarse sand can be questioned, since the required adaptations in the concrete have additional costs.

3.5 Impact assessment

Impact assessment was performed according to the baseline methods of the latest CML guidelines [5]. Dutch factors were used for the normalisation. Next to the environmental profile according to CML, the themes 'total primary energy consumption' [MJ] and 'total final waste' [kg] were calculated for communication purposes.[1]

As an experiment, the impact assessment method for land use by Lindeijer [3] was applied. This method distinguishes between occupation and transformation of land. For both types of land use two indicators are distinguished: one for biodiversity and one for life support functions. The level to which all land use activities are related is called the reference state[2]. In the LCA of finer sand in concrete the average quality in a region was chosen as a reference state, since this is most compliant with the Dutch policy. Choosing an average quality level in a region as a reference state can be seen as a more anthropocentric point of view, where as choosing a maximum quality level as a reference state can be seen as a more ecocentric viewpoint. The reference period for including renaturation of sites was either the ending of property ownership or (if unknown) 100 years.

Three typical constraints of this method were important for this study:

- biodiversity of marine systems cannot be calculated at the moment. The extraction process of marine sand could therefore only be assessed for life support indicators;
- how people perceive land use is not included, since this a subjective issue;
- flora is regarded as the most important indicator for land use effects. Fauna is not included in the method.

The land use method was rather complex to apply in practice, mainly caused by the different characteristics between land use and other environmental effects. Land use assessment requires data that are normally not collected for LCA purposes, fluctuate in time and refer to situations in the past, the present and the future, and are therefore hard to find. The practitioner needs to have sufficient LCA experience, in order to evaluate and interpret the outcome of calculations correctly, due to limitations in the methodology. (For example: biodiversity in marine ecosystems is not taken into account.) Results are also strongly affected by methodological choices. (For example: is the average or maximum reference state chosen?) This study demonstrated that it is essential to know the background (representativity) of the data that are used. These findings comply with the conclusions drawn in the preface of (Lindeijer et al. [3]).

4 Results

Because of the large number of compositions studied, the environmental profiles were presented per environmental effect on a 0–100% scale. **Figs. 1** and **2** show the environmental themes energy consumption and final waste. **Figs. 3–5** present the impact categories that show the greatest magnitude in normalisation. The most important normalised experimental land use effects are shown in **Figs. 6–8**.

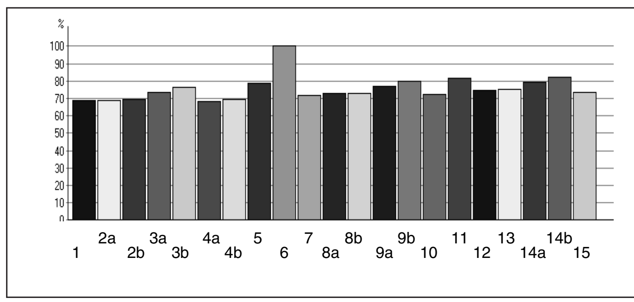

Fig. 1: Energy

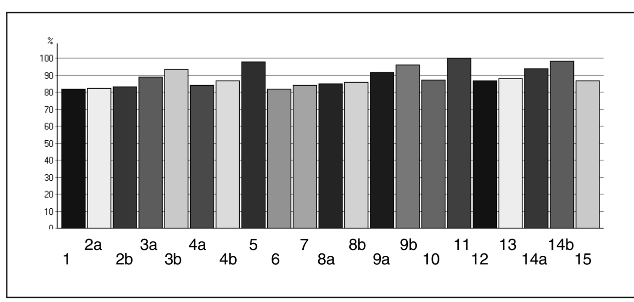

Fig. 2: Waste

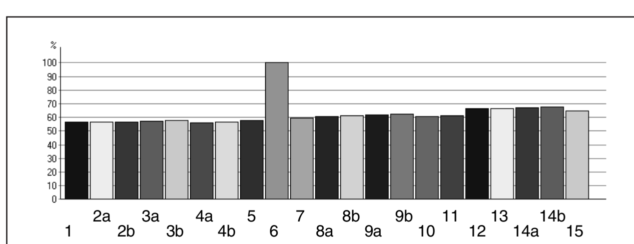

Fig. 3: Photochemical oxydant formation

[1] Energy use and waste are not environmental effects in themselves, but cause environmental effects such as depletion of resources, greenhouse effect, (eco)toxicity effects, etc.

[2] The reason why a reference state is used is threefold [3]:

1. The no-impact situation (related to no human land use) does not have an indicator value zero (in contrast to emissions) but a maximum or average nature value. The reference state expresses this no-intervention value.
2. Biodiversity impacts should be expressed in relative terms.
3. To assist in the decision support function of LCAs including land use.

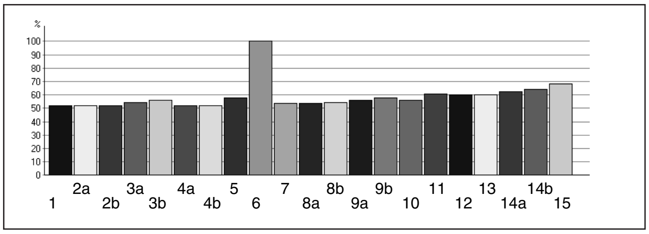

Fig. 4: Acidification

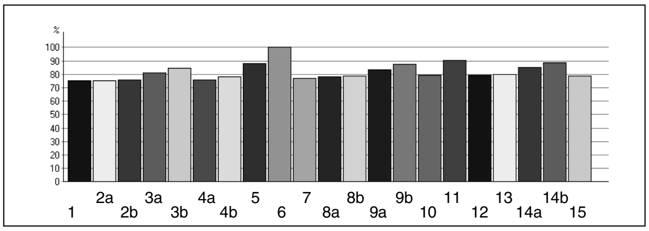

Fig. 5: Global warming

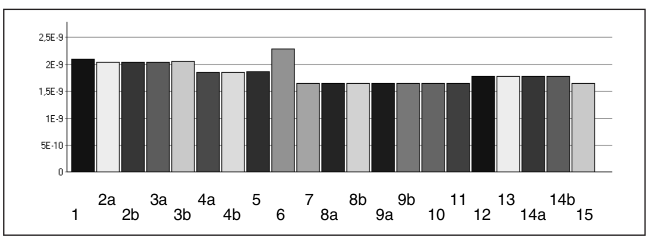

Fig. 6: Land use ETav (transformation – biodiversity during activity)

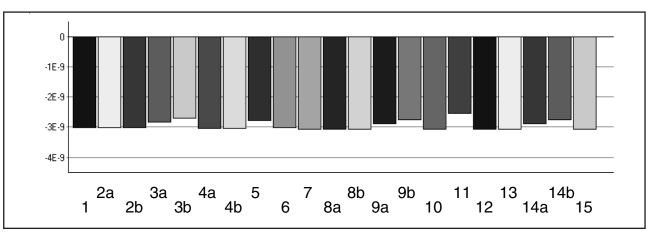

Fig. 7: Land use ETRav (transformation – biodiversity during renaturation)

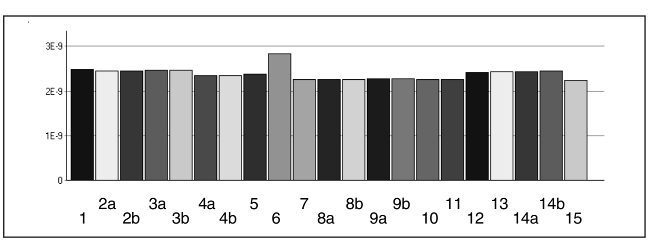

Fig. 8: Land use LTnpp (transformation – life support during activity)

5 Evaluation

5.1 Process contributions

Four types of processes contribute most to the environmental effects:

CML impact categories:

- transport of raw materials to the concrete producer;
- the production of cement.

land use impact categories:

- land renaturation after gravel extraction. Note that in Lindeijer's data set this process contributes with a negative environmental impact because the final land use situation has a higher quality than the current average situation. However, the net effect of gravel is still positive because of the land use impact by transport;
- the production of concrete, only with respect to land use effects (![3]).

The consequences of the use of fine sand in concrete are related to these processes (**Table 2**).

Evaluating the results, considering the limits of the data and the methods, leads to the following qualifications of Table 2:

a) the results on the usual impact categories are mainly based on energy consumption and are considered to be reliable;
b) the beneficial effects of gravel on land use are an artefact of the data set from [3], which heavily relies on one gravel extraction project where nature is developed after the extraction has finished. This is not representative for modern modal gravel extraction sites in the Netherlands, which are more likely to be converted into recreational areas;
c) the small land use impact of marine sand is partly due to the fact that marine systems cannot be assessed regarding biodiversity and should therefore be treated with suspicion;
d) fine sand scores better than coarse sand due to the chosen economical allocation rule. The value of fine sand is less than the value of coarse sand, which automatically results in lower environmental impacts from fine sand. Economic data change in time, which could result in different conclusions over time. However, a lower land use per ton of extracted concrete sand is logical for sites that would give a higher yield when finer sand would be co-produced. This benefit could become neutralized when new extraction sites with a lower yield become profitable.

[3] This was not expected. We focused on land use effects of minerals and the land use of a production plant (including the energy/electricity production processes) turned out to be important.

Table 2: Environmental consequences of the changes in the concrete composition, necessary because of the replacement of traditional coarse sand by finer sand

Changes in the concrete composition	Changes in CML baseline impact categories	Changes in experimental land use impact categories
Increasing the finer sand content (reducing overall coarseness of the sand)	No shift in environmental effects	***Lower*** environmental effects
Increasing the share of (Dutch) marine sand	No shift in environmental effects	***Lower*** environmental effects
Increasing the cement content	***Higher*** environmental effects	No shift in environmental effects
Decreasing the gravel content (e.g. a higher cement content)	No shift in environmental effects	***Higher*** environmental effects
Increasing the superplasticiser content	***Similar*** environmental effects	***Similar*** environmental effects
Increasing transportation (especially per truck)	***Higher*** environmental effects	***Similar*** environmental effects

5.2 Sensitivity analyses

Sensitivity analyses on transport showed that transport strongly influences the conclusions about preferable and less preferable concrete compositions. The analyses also showed that the importance of cement is hardly affected by assumptions about the content of cement.

5.3 Evaluation of the land use method

The experimental land use method could be applied and resulted into quantitative indicator results that do not conflict with common sense. Most alternative compositions show better scores than the reference. This was expected since the main reason for such alternatives is to reduce the land use impacts. An interesting exception are the compositions requiring long distance transport over land (6 and 12 to 14b), where land use for transport seems to neutralize or even exceed the benefits in the extraction phase. Such shifts in environmental impacts can only be evaluated using LCA. Still, most results are difficult to interpret, due to several limitations, as shown above. Especially the omission of biodiversity of marine systems was regarded as a severe limitation in this specific study.

5.4 Benefits from the review process

The review process was definitely considered to be beneficial. The discussion with the stakeholders improved the whole of the LCA study, and especially the system description. The stakeholders were unanimously positive about the process. Their knowledge about LCA was improved by the explanations in the panel.

The LCA expert also had a constructive contribution, especially with regard to methodological issues.

6 Conclusions

The results show that the application of finer sand in concrete results in:

- lower (better) land use effects, of up to $2.8*10^{-10}$ part of the total Dutch yearly environmental land use load per m^3 of concrete;
- roughly equal environmental effects, when superplasticiser is used in the concrete composition;
- higher (worse) scores, of up to $4.6*10^{-10}$ part of the total Dutch yearly environmental load per m^3 of concrete, on other environmental effects in situations where extra cement or extra transport are required.

The trend in the conclusions seems valid for various types of concrete. Reinforcement and other technical corrective measures however could result in different conclusions.

If the results would also be valid for B35 concrete types (50% of the prefab market), the application of finer sand in concrete would result in better land use scores of up to 0.22% and worse scores on other environmental effects of 0.37% of the total Dutch yearly environmental load. In absolute terms, this is rather substantial.

The two central questions were answered as follows;

1. **Should the application of finer sand in concrete be stimulated, based on the LCA?**
   Hardly any negative environmental effects are anticipated when finer sand is used to relief the Dutch land use dilemma, provided that the concrete composition is only corrected by adding superplasticiser. Other corrective measures will lead to an increase in environmental impacts.
   The decision-maker ought to be aware of the experimental character of the land use impact assessment method, as well as the fact that marine systems cannot be fully assessed on land use effects. Furthermore, it is important to realise that the current situation has been studied and therefore the impact of exploiting new extraction sites or a shift in the yield of existing extraction sites could not be assessed. For the same reason a shift in the price of (fine) sand, which would have an effect on the economic allocation of environmental impacts, could not be taken into account.
2. **If so, which sand types from which origin are preferred?**
   The preferred sand types are terrestrial or marine sands from the Netherlands or direct surroundings, providing that the composition is not corrected by adding crushed aggregate (2–6 mm) from other sources because of the extra transport involved. Coarse sand types that require transport over a long distance are less favourable, even when compared to fine sand from nearby sources needing corrective measures. The turning point is determined by the distance and the means of transport, and varies with concrete composition.

As often the case in the construction sector, most environmental impacts included in the usual sets of category indicators relate to energy use. Therefore, it was not surprising that the reference, which is cost-optimised, has the lowest impacts on these categories. In this case, LCA without land use would have given an incomplete and therefore misleading result.

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